IL NUOVO CIMENTO **39 C** (2016) 367
DOI 10.1393/ncc/i2016-16367-9

Colloquia: SEA2016

OMPs for the ^{6}He + ^{209}Bi halo system from a ^{208}Pb(^{7}Li,^{6}He)^{209}Bi reaction analysis

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received 28 November 2016

Summary. — Angular distributions of transfer reaction ^{208}Pb(^{7}Li,^{6}He)^{209}Bi were measured at $E_{\mathrm{lab}}(^{7}\mathrm{Li})$= 21.2, 24.3, 25.67 and 28.55 MeV. By fitting the experimental data with the theoretical frameworks of Distorted Wave Born Approximation (DWBA), the optical model parameters of the halo nuclear system ^{6}He+^{209}Bi were extracted. The breakup threshold anomaly (BTA) was observed clearly in the imaginary potential, and a further decreasing trend in the deep sub-barrier region was observed for the first time in a halo system. Furthermore, the dispersion relation is found of no use to describe the connection between the real and imaginary parts.

1. – Introduction

The nuclear interaction is a fundamental ingredient in the study of mechanisms of nuclear reactions. The optical model potential (OMP) is universally adopted to phenomenologically describe the interaction of nuclear collisions. With decades of researches, some basic properties of the OMPs of tightly bound systems have been observed, *e.g.* when the interaction energy gets close to the Coulomb barrier, a strong energy dependence will be presented in both the real and imaginary parts due to the strong coupling between intrinsic degrees of freedom and reaction dynamics, which is known as the threshold anomaly (TA) [1]. This behavior is characterized by a sharp decrease of the imaginary potential as the bombarding energy decreases towards the Coulomb barrier, associated with a localized bell-shaped structure around the barrier in the real part. The dispersion relation which bases on the causality principle, can be used to connect variations of the real and

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imaginary parts [2]. Nowadays, the OMPs of weakly bound systems have attracted great interests [3], because of the particular properties of the potential arising from the exotic nuclear structure. A most significant features of the OMPs of weakly bound system is that, in the sub-barrier energy region, where the Coulomb repulsion effect is dominant, the depth of imaginary potential increases as the energy reduces. This abnormity indicates that the absorption continues to be strong even with a interaction energy lower than the Coulomb barrier. This phenomenon strongly relates with the breakup process of weakly bound system, thus it is called the breakup threshold anomaly (BTA) [4-6]. However, due to the large data uncertainties and lack of enough experimental points [7], it is difficult to draw a distinct conclusions on the energy dependence of the OMPs of halo nuclear systems. Furthermore, even for the stale weakly bound systems, we are still far from the comprehensive understanding on the properties of the OMPs, *e.g.* the increasing of the imaginary potential followed by a decreasing trend at a sufficiently low energy region is barely observed [3, 8, 9], and the application of the dispersion relation is still debatable [2, 6, 10].

In view of this fact, we try to use the transfer reaction to study the OMPs of a halo nuclear system. The greatest advantage of the transfer method is that the stable beam can be used to study the OMPs of the halo system, yielding fairly accurate results. In the previous work [10], the one-proton transfer reaction ^{208}Pb(^{7}Li,^{6}He)^{209}Bi was adopted to study the OMPs of the halo nuclear system ^{6}He + ^{209}Bi in the exit channels at near- and above-barrier energies. With the favor of the transfer method, the BTA of the halo system ^{6}He+^{209}Bi was observed clearly for the first time, and a distinct conclusion can be drawn that the traditional dispersion relation is not suitable for the weakly bound system. In the present work, we still adopted the one-proton transfer reaction of the ^{7}Li+^{208}Pb system but within the deep sub-barrier energy region, to investigate the behavior of OMPs at sufficient low energies.

2. – Experiment

The experiment was carried out at the China Institute of Atomic Energy, Beijing. A ^{208}Pb target with thickness of about $120\,\mu$g/cm^2 on a $20\,\mu$g/cm^2 ^{12}C backing was bombarded by a ^{7}Li beam provided by the HI-13 tandem accelerator, with a current of about 40 pnA. Reaction energies in the laboratory frame were 21.2, 24.3, 25.67 and 28.55 MeV. Two Si-detector telescopes were fixed at the backward angle region, with the angle coverage of 99°–127° and 144°–171°, respectively. Each telescope contains three layers of Si-detectors, a $20\,\mu$m single-side strip detector (16 channels), a $60\,\mu$m double-side strip detector (16× 16 pixels), and a $1000\,\mu$m quadrant silicon detector as the E_{R} detector. An array including 8 PIN detectors was mounted to measure the elastic scattering of the ^{7}Li+^{208}Pb, with a coverage from 20° to 68°. Another two PIN detectors were placed at ±15° to monitor the beam quality.

3. – Results and discussions

The angular distributions of transfer reaction ^{208}Pb(^{7}Li,^{6}He)^{209}Bi at different energies are shown in fig. 1. Except for the lowest energy, $E_{\mathrm{lab}} = 21.2$ MeV, the angular distributions with proton transferred from ^{7}Li to different excited states of ^{209}Bi, as labelled in fig. 1, were obtained. The experimental data were then fitted by the DWBA method, to extract the OMP parameters of the halo system ^{6}He + ^{209}Bi. The calculations were performed with the code of FRESCO [11]. The fitting results are also presented in fig. 1

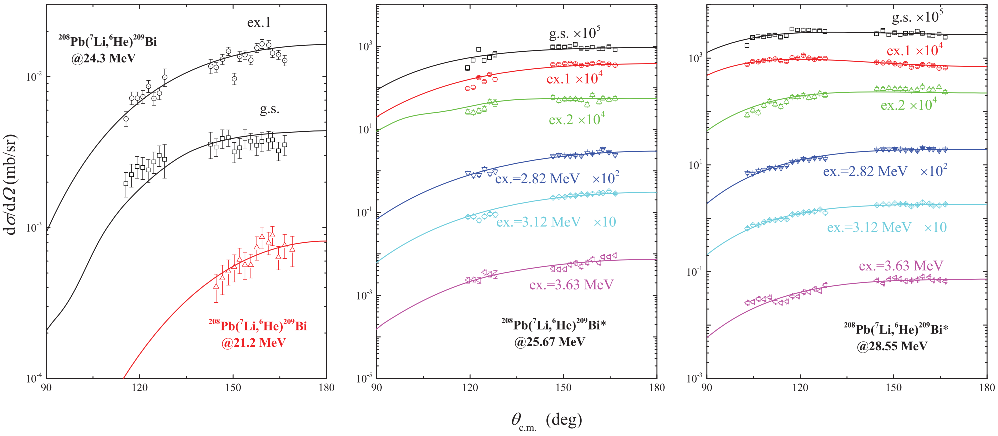

Fig. 1. – Angular distributions of ^{208}Pb(^{7}Li,^{6}He) reactions for transferring to different excited states of ^{209}Bi at $E_{\mathrm{lab}} = 21.2$, 24.3, 25.67 and 28.55 MeV. The solid curves are the fitting results by DWBA.

by solid curves. In the fitting process, the geometry parameters of the optical potential were fixed at $r_{0V} = 1.02$ fm, $a_V = 0.70$ fm, $r_{0W} = 1.25$ fm, and $a_W = 0.95$ fm [10]. The energy dependence of the strengths of the real and imaginary parts at the sensitivity radius 13.5 fm is shown in fig. 2, with the results at above-barrier energies taken from

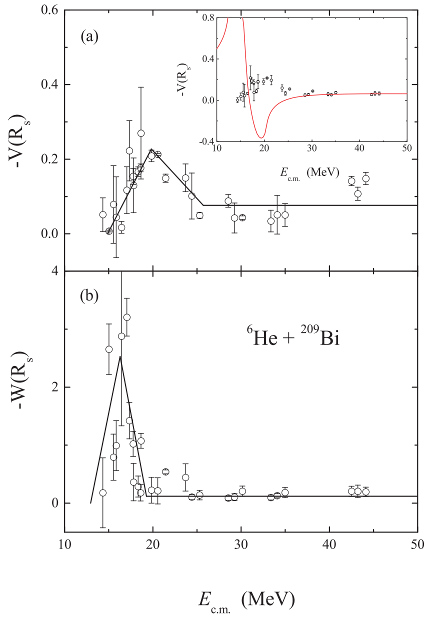

Fig. 2. – Energy dependence of the real (a) and imaginary (b) parts of the OMP at the sensitivity radius of 13.5 fm. The solid curves show the linear segment fitting results for the real and imaginary potentials. The results at above-barrier energies are taken from ref. [10]. The solid curve in the inset presents the calculation result for the real potential according to the dispersion relation with the variation of the imaginary part.

ref. [10]. The errors of potential depths were derived by χ^2 analysis as described in ref. [12], with a confidence level of 68.3%.

As shown in fig. 2, strong energy dependence are observed for both the real and imaginary parts, which mainly arise from the dynamic polarization potential (DPP), containing all effects of couplings to non-elastic direct reaction channels. For the imaginary part, according to the linear fitting result, the depth increases first as the interaction energy decreases in the sub-barrier region, demonstrating the BTA phenomenon. With the energy reduced further, the depth of the imaginary potential begins to decrease. This is the first time that the decreasing trend in the imaginary potential is observed within a sufficient low energy region in a halo nuclear system. According to extrapolation of the linear fitting result, the reaction threshold energy, where the imaginary potential vanishes, can be derived, as about $0.73V_{\mathrm{B}}$. This threshold indicates that all the non-elastic channels are effectively closed by the Coulomb barrier, and reactions occur only when the interaction energy gets above this threshold energy to overcome the repulsive Coulomb barrier.

On the other hand, the applicability of the dispersion relation is investigated for this halo nuclear system. The calculation result for the real potential according to the dispersion relation with the variation of the imaginary potential is shown in the inset of fig. 2(a). According to the dispersion relation, if W decreases with energy increasing in a narrow range, the corresponding ΔV will generate a strong repulsive effect in the same energy range [2]. However, in contrast to this, a sharp peak is present in the real part of the OMP, which manifests itself as an attractive potential. This result indicates that the dispersion relation, which is based on the causality principle, does not hold for the weakly bound system. However, in refs. [4,6] the authors still tried to use the dispersion relation to describe the connection between the real and imaginary parts of the OMPs of weakly bound systems. Due to the large uncertainties of the results, it is hard to draw a specific conclusion. Therefore, whether the dispersion relation is suitable for the weakly-bound system is still an open question, and deserves further investigation.

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This work is supported by the National Key Basic Research Program of China (No. 2013CB834404), and the National Natural Science Foundation of China under Grants No. 11505293, No. 11375268, No. 11475263, No. U1432246, No. U1432127, and No. 11635015.

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